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14. ABSTRACT

The Challenge: Designing a light-weight, low-cost control and data system for the engine controller and a remote data system for propellant conditioning for an Air Force SBIR Phase III vortex propulsion flight demonstration program. The Solution: Developing a low cost, off-the-shelf embedded system with minimal manpower and increased flexibility using a custom NI LabVIEW application and the NI CompactRIO platform to deterministically control a liquid rocket engine and its associated feed systems. Additionally developing an easy to setup remote temperature monitoring system.

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Real-Time Flight Engine Controller Using NI LabVIEW and CompactRIO Hardware

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Category:

Advanced Control Systems

Products Used:

cRIO-9022 Controller
cRIO-9113 4 slot FPGA backplane
NI 9205 32-Channel ±10 V, 250 kS/s, 16-Bit Analog Input Module
NI 9475 8-ch 24VDC Sourcing Digital Output, 1A/ch
NI 9476 32-Channel 24VDC Sourcing Digital Output
NI USB 9213 16-Channel USB Thermocouple Module
Labview Real-Time Module
Labview 2009

The Challenge:

Designing a light-weight, low-cost control and data system for the engine controller and a remote data system for propellant conditioning for an Air Force SBIR Phase III vortex propulsion flight demonstration program.

The Solution:

Developing a low cost, off-the-shelf embedded system with minimal manpower and increased flexibility using a custom NI LabVIEW application and the NI CompactRIO platform to deterministically control a liquid rocket engine and its associated feed systems. Additionally developing an easy to set-up remote temperature monitoring system.

Body Text:

ORBITEC is focused on the development and demonstration of innovative, low-cost components for propulsion systems, including vortex-cooled thrust chamber assemblies for boost and upper stage applications. The vortex-cooled thrust chamber assembly employs ORBITEC's patented vortex combustion process to confine propellant mixing and burning to the central core region of a coaxial vortex flow field. This enables dramatic cost savings through robust design margins leading to extremely high durability, reliability, and reusability in engines that are inexpensive to manufacture and maintain.

The current Air Force Small Business Innovation Research (SBIR) Phase III program is focused on demonstrating the vortex-cooled engine technology in a flight demonstration vehicle. ORBITEC's thrust chamber assembly and ignition system will be integrated into a Garvey Spacecraft Corp. "Prospector" Class Launch Vehicle (Figure 1). ORBITEC will also provide ground support equipment for propellant conditioning of the fuel system. A successful flight demonstration will elevate the technology maturity to a level which demonstrates a prototype in an operational environment.

Figure 1: A Garvey Spacecraft Corp. “Prospector” Class Launch Vehicle in Flight

Two National Instrument systems were selected for this program. The CompactRIO platform was selected for the engine flight controller system. This system will be located on the actual flight vehicle and is designed to control the vehicle autonomously. A number of requirements made the CompactRIO platform the best choice for the controller. The primary reason was the need for real time, deterministic control of the propellant feed systems and engine as well as data logging capability. Since the controller would also be installed on the vehicle, the system also needed to be reliable and extremely rugged. Key factors to consider were low power consumption, weight, size and non-volatile memory storage. In an attempt to further reduce overall vehicle weight, the chassis was modified as shown in Figure 2. Creating open slots in the sides as well as cutting out the end reduced the overall weight. In the initial stages of the flight demonstration program the specific I/O counts and current ranges were undefined. By choosing a system that was modular in design, any number of C Series I/O cards could be identified at a later time to handle the required I/O counts. This provided the needed flexibility.

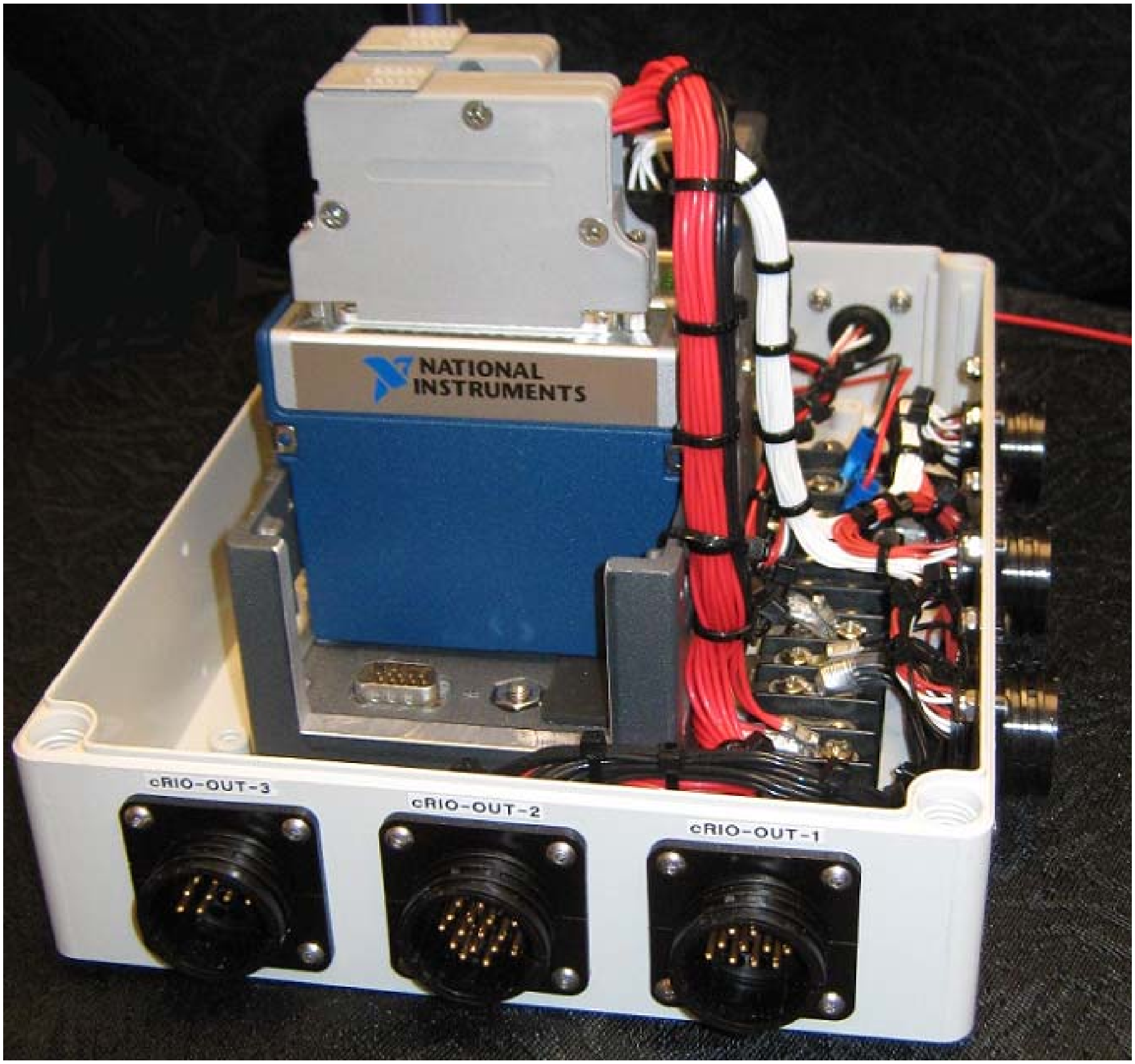

Figure 2: cRIO System with Metal Cut Out of the Chassis.

A self contained USB temperature measurement system was selected for the ground support equipment temperature system. As the name implies, this system is located on the ground and monitors propellant temperatures in a closed loop cooling system as well as the flight vehicle tank temperatures during vehicle loading. The USB 9213 module was selected for the temperature monitoring system for its flexibility and ease of use. It includes on board cold junction compensation and a high channel count. For checkouts, a laptop can easily be connected to monitor temperatures locally at the launch pad. For remote operations the same programming can be used with an Ethernet C Series single module carrier. In my situation, however, I was able to use an existing USB extender which provided the same remote functionality.

As a small business, ORBITEC has limited personnel and resources for developing custom control system hardware and software. By using off-the-shelf real-time embedded control hardware that has been tested and proven by National Instruments, only one engineer was required to design and develop the entire system. No low level programming and specialty I/O interfaces had to be designed for this system. Additionally, LabVIEW and the LabVIEW Real-time module were all that were necessary to develop the custom software. The system required determinism, but not speed. As such the NI Scan Engine was used to acquire and control the signals in the system. This saved significant development time.

The engine flight controller system software architecture consists of a human machine interface (HMI) program developed for a host computer. The target CompactRIO runs a separate program. The target is configured to run even in the event of the loss of the wireless Ethernet communications. The reliability of the wireless system in not guaranteed considering the range of the flight vehicle. Prior to launch, the control system is run in manual mode with the HMI program sending commands to the vehicle and the target relaying data to the host computer. The use of a limited set of network-published shared variables is used as a seamless interface for this mode of communications. Figure 3 shows the HMI user display. To assist the operator to quickly diagnose problems at the launch pad the data displays are color coded. The program compares the data value with the min and max range retrieved from Measurement Automation Explorer. If the data is out of range, the display label background will turn red. This indicates the instrument or wiring may be bad. The program also compares the data value with a “go/no go” range for each channel. This range is loaded at the start of the program from a predefined configuration file. If the data is within the “go” range the display background turns green. This allows the operator to quickly scan the HMI display prior to initiating automatic mode.

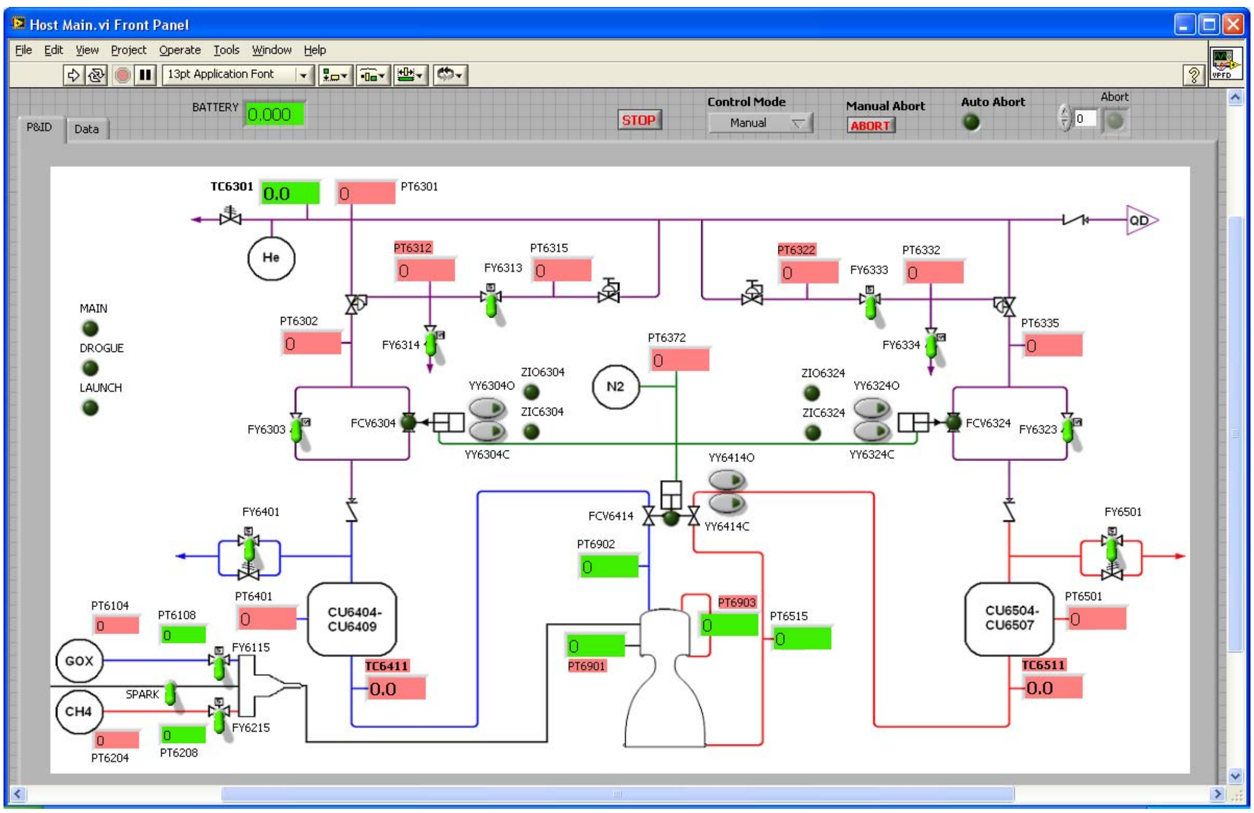

Figure 3: HMI User Display Screen.

Once the propellant tanks are filled and all conditions are “go”, the operator uses the HMI program to set the target to automatic mode. In automatic mode the target runs autonomously. It still continues to transfer data to the HMI computer for real time display, however if communications are lost, the target program will continue to run. In automatic mode, the target runs a pre-loaded sequence of operations from a tab delimited file that has been sent via FTP. The target also conducts limit checking on a set of critical data signals. If any of the signals is out of range as compared to a user-defined range of values, the system can automatically abort the launch if required. Once in flight, the target will continue to log data to both the CompactRIO onboard memory as well as an external solid state USB drive. If the controller doesn’t survive the return vehicle impact and data can not be retrieved via

FTP, I can still recover data off of the solid state drive. The controller also monitors battery power and will conduct an orderly shutdown of the data logging prior to a loss of power.

The software architecture for the ground support equipment temperature system is very simplistic. By using LabVIEW software and Measurement Automation Explorer for channel configurations and task definition, the program was literally completed in a matter of days. Figure 4 shows the HMI display for this system. Because the propellant conditioning can take several hours, the user has the option of modifying the data acquisition rate, the display rate and the record rate within the program depending on what the system response is doing at any particular time. Each time the program is run, the program automatically increments a pre-defined data file name. This LabVIEW program was built as an executable with an installer program to allow it to be used on any laptop available in the field.

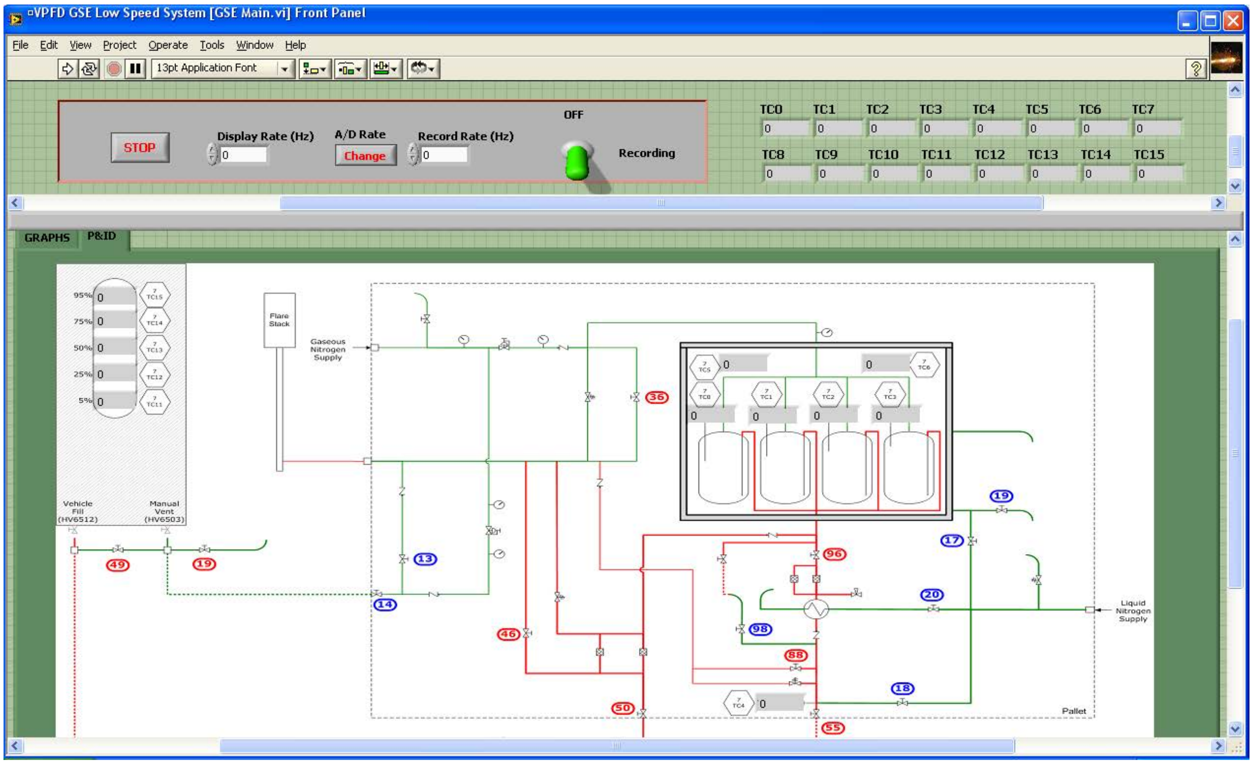

Figure 4: Ground Support Equipment Temperature System Display Screen.